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A Gamma-Ray Imaging Spectrometer for NDA Measurements

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Gamma radiation has long been used as a diagnostic for detection and characterization of materials used in the nuclear power industry and the nuclear weapons complex. This highly penetrating radiation is ubiquitous to the materials of interest, providing an excellent diagnostic in view of its directionality and characteristic energy spectra. The former may be used to localize material, the later to identify its type. Although the energy spectra have been exploited to a high degree with various detectors of differing energy resolutions, little has been done with the directionality other than "proximity imaging." In this type of material localization, an omnidirectional detector is passed near a suspected source location as one monitors the count rate as a function of position. Although effective, this type of imaging provides information about material location and distribution comparable only to the distance of closest approach. It does not make full use of the information in the radiation field.

This paper summarizes the work on GRIS, the Gamma-Ray Imaging Spectrometer, an instrument designed and built at LLNL which relies on coded aperture imaging to produce faithful, energy-specific images of radioactive material. GRIS has been used in various field trials including arms control measurements to count nuclear weapons on an emplaced peacekeeper missile,[1] transparency measurements of plutonium "shapes,"[2] and extensive trials in locating holdup in gaseous diffusion plants.[3] It is made possible by a position-sensitive detector developed at LLNL [4] which has a position resolution better than 2 mm throughout an energy band from ~ 60 keV to ~ 500 keV. The detector is based on a CsI(Na) scintillator coupled to a position-sensitive photomultiplier tube. The detectors provide an energy resolution comparable to a standard NaI(Tl) detector allowing one to generate images based on specific spectral features. This can be used to generate isotope specific images. GRIS comprises a total of four detectors used in parallel to provide a total active area of ~ 60 cm^2.

Coded apertures can be employed to make an image where normal imaging optics are ineffective.[5] The technique makes use of a shadow mask placed a distance, f, in front of a position-sensitive detector to project a direction specific pattern onto the detector. The resulting data are deconvolved using cross correlation with the mask pattern, to provide an image of the radiation field. Although coded apertures are capable of producing artifact free images because they autocorrelate to a delta function, one must take care to remove spurious spatial modulations at the detector. Such modulations may arise from detector nonlinearities, variations in quantum efficiency or scattering off of shielding around the detector. Because the image is generated from variations in counts across the detector any such spurious variations will produce spurious features in the deconvolution. Although the former two modulation factors can be removed by careful detector calibrations, the last is found to be scene specific requiring *in situ* background measurements. We perform these by taking equal time mask and anti-mask exposures. (The anti-mask has the blocked and open pixels exchanged from those of the mask.) Because all regions of the summed detector see equal exposure through the aperture pixels, no shadow pattern from the coded aperture is present. Any remaining spatial variations in counts are spurious and can be removed before deconvolution is performed. Since both the mask and anti-mask represent valid coded aperture patterns, both exposures can be deconvolved to produce images from the entire exposure period.

The deconvolution produces quantitative count rates with a position-resolution, Δx, at the object which is the same as that of a pin hole camera:

$$\Delta x = d\ (a/f)$$

where d is the distance from the camera to the target, a is the smallest mask feature and f is the distance between the mask and the detector. However, unlike a pin hole camera, half of the mask is open, providing a $\sqrt{N}$ improvement in the signal-to-noise ratio over that of a pin hole camera for a single point source. Here, N is the number of open holes in the mask which for our 19 by 17 pattern represents more than a 12 fold improvement.

Gamma-ray/visible light overlay images obtained with GRIS in a number of trials will be presented. In addition, the current state of system upgrades, including commercialization together with RMD, Inc. will be reviewed.

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References:

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